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Article

Spatiotemporal assessment and prognostic modeling of groundwater level in Mymensingh, Bangladesh: A longitudinal study utilizing ARIMA time-series forecasting

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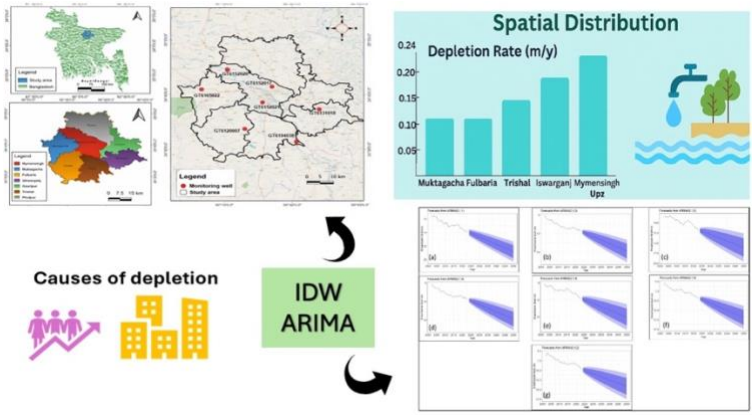
Graphical abstract



Highlights

- *This study found a persistent decline in groundwater levels in Mymensingh region, Bangladesh.*
- *Over-extraction likely contributed to the decline in groundwater levels, which resulted from population growth and developmental activities.*
- *The depletion rates were quantified, ranging from 0.09 m/year to 0.24 m/year.*
- *ARIMA forecast model found critically low groundwater levels in the studied wells by 2050.*

Abstract

Groundwater plays a crucial role in meeting the demands of domestic, agricultural, and industrial sectors worldwide. The growing reliance on groundwater resources has led to excessive withdrawal that exceeds natural recharge for an extended period due to population growth, urban development, and other environmental factors. This study analyzed groundwater level data from Mymensingh, Bangladesh, to determine the spatiotemporal pattern, the rate of groundwater level depletion, and the state of predicted groundwater level by 2050. Weekly groundwater level data from seven monitoring wells were collected from the Bangladesh Water Development Board (BWDB) from 2002 to 2023. Spatial interpolation using inverse distance weighting (IDW) and an ARIMA time series model was employed for the analysis of long-term water level forecasting. The results showed groundwater level fluctuations and depletion at different monitoring wells of the study area. Of the 7 monitoring wells, GT6152021 experienced the highest depletion (0.24 m/y), and GT6152020 was the lowest (0.09 m/y); both

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were in Mymensingh Sadar. The depletion rates of other wells fluctuated between 0.15 and 0.19 m/y. The groundwater level data from all monitoring wells revealed a declining trend, indicating that the groundwater resources were used indiscriminately in the studied region. The fitted ARIMA (0, 1, 0) forecasting model for well GT6152021 observed the groundwater level to be at 25 m by 2050, and the other wells be between 17.5 and 19.5 m. These results will help planners and policymakers allocate groundwater resources among agricultural, domestic, and industrial uses.

1 Introduction

The developing nations around the world rely on groundwater for its economy, society, and ecology (Rashid et al., 2022). However, the availability of the freshwater resources is under threat, as many aquifers are being depleted and extraction is exceeding natural recharge (Kroes et al., 2019). Groundwater storage presents enormous potential in Bangladesh due to its tropical monsoonal climate and favorable hydrological and geological conditions (Zahid and Ahmed, 2013). Since the 1980s, groundwater extraction in Bangladesh has expanded significantly, supplying nearly all water demands, including about 79% for irrigation, livestock, domestic, and industrial uses (Shamsudduha et al., 2009; Ghosh et al., 2015; Mainuddin et al., 2020). In Bangladesh, aquifers are being depleted due to increased groundwater exploitation, accelerated dry-season paddy cultivation, and reduced baseflow to rivers (Taylor et al., 2013).

The degree of groundwater recharge is largely governed by the balance between abstraction and sub-surface geological conditions. As a result of excessive groundwater abstraction, water shortages in shallow aquifers are beginning to pose a serious threat worldwide. Climate variability significantly affects global groundwater resources by altering recharge rates (Ajami et al., 2012). However, the effects of climatic variables on groundwater recharge remain poorly understood, as they depend on several interacting factors, including vegetation, land-use patterns, soil types, and geological settings. In addition, the response of groundwater systems to global warming is a complex issue (Zaman, 2007; Green et al., 2011). Effective groundwater resource management, therefore, requires a comprehensive understanding of storage volume, discharge rates, recharge rates, and the application of cost-effective extraction strategies (Ahmeduzzaman et al., 2012).

The key factors influencing groundwater yield potential include hydraulic properties and aquifer characteristics, long-term trends in static water level variation, recharge and depletion behavior, and the safe yield of the groundwater basin (Green et al., 2011). In Dhaka, Bangladesh, groundwater levels declined at rates of 0.6–2.4 m/year, with greater declines observed in central areas compared to peripheral zones (Moshfika et al., 2022). Due to groundwater pumping in northwestern Bangladesh, a dynamic drawdown ranging from 0.14 to 15.24 m per m^3/s of well discharge, with an average of 5.69 m per m^3/s, was reported (Mojid et al., 2019). Furthermore, noticeable declines in groundwater levels were observed in Habiganj and Sunamganj, ranging between 8 and 10 m. Several studies have reported that groundwater levels in parts of the Barind Tract in northwest Bangladesh declined by at least 10 m over the past 14 years (Ali et al., 2012; Ali et al., 2023; Hossain et al., 2024; Rahman et al., 2025). Additionally, during the dry season, groundwater levels at specific well sites in Mymensingh and Kishoreganj districts were found to be as deep as 14 m (Kutub, 2015).

Seasonal variations in recharge and storage can lead to groundwater-related hazards, including droughts, floods, and water scarcity (Taylor et al., 2013). Consequently, changes in intra-annual groundwater level fluctuations may adversely affect both society and the environment. A significant decline in groundwater levels occurs when withdrawal exceeds natural recharge over prolonged periods. Therefore, groundwater level assessment and its prediction serve as a core component to aid sustainable groundwater management planning. Continuous groundwater monitoring is essential to understand the dynamic equilibrium or unstable behavior of aquifer systems and to address associated sustainability challenges (Kirby et al., 2015; Abdullahi and Garba, 2016; Mainuddin et al., 2020). Rainfall plays a critical role in groundwater replenishment as well as in generating surface runoff. The main determinants of an aquifer's yield potential include its hydraulic properties, long-term groundwater level trends, recharge and depletion characteristics, and the basin's safe yield (Basunia et al., 2015). Although several studies have been conducted in Bangladesh, a comprehensive, location-specific assessment is still required to accurately evaluate the current condition of groundwater reserves.

Therefore, this study aimed to visualize the spatial distribution and analyze the groundwater level depletion rate in Mymensingh and its surrounding areas, as well as to predict groundwater levels for individual monitoring stations up to the year 2050 using the ARIMA model. To the best of the authors' knowledge, no previous study has

simultaneously examined both recent groundwater dynamics and future groundwater status in this area; this research seeks to address this knowledge gap. The identified trends reflecting the general trajectory of groundwater resource change can be used to assess groundwater sustainability.

2 Materials and methods

2.1 Study area

The study area comprises Mymensingh and its surrounding upazilas, which are Trishal, Iswarganj, Fulbaria, and Muktagacha. The area is located from 24.04 °N to 25.05 °N latitudes and from 89.65 °E to 91.25 °E longitudes, at mid north of Bangladesh (**Fig. 1**). On the north, it is bordered by Phulpur; on the south, it is bordered by the Trishal, Bhaluka, and Gazipur; on the east, by the Netrokona and Kishoreganj districts; and on the west, by the Sherpur, Jamalpur, and Tangail districts (Hussain et al., 2016). The study area, located in the Madhupur Tract in Mymensingh, is dominated by clay-textured soils rich in iron and aluminum, which exhibit a high degree of aggregation (Akhter et al., 2019b). Flood plain, grey piedmont, hill brown, and terrace make up the district's soil composition. The average temperature of the study area is 25.62°C, with total annual rainfall ranging from 1,500 to 3,300 mm (BMD, 2019). There are small rivers, marshes, canals, and woodland also present in the area, in addition to the Brahmaputra.

2.2 Data preparation

Weekly groundwater level data were collected from the Bangladesh Water Development Board (BWDB) from 2002 to 2023, which has been in charge of managing the country's 1,250 monitoring wells since the early 1960s. The data from 7 monitoring wells in the Mymensingh region were considered for the study. The BWDB used a standard horizontal datum called the Public Works Datum (PWD) to determine the groundwater level at each station (Shamsudduha et al., 2011). **Table 1** displays the specifics of the monitoring wells. All data used in the study area are statistically significant at the 99% confidence level (p-value <0.001).

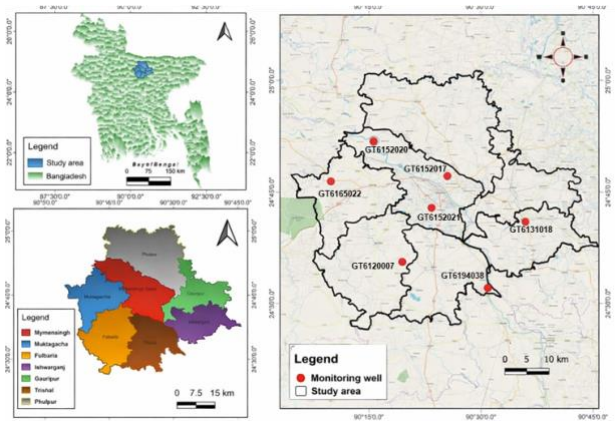

Figure 1. *Location of the study area in Mymensingh, Bangladesh.*

Table 1. *Details of the monitoring wells in the study area.*

Location	Station ID	Latitude (degree N)	Longitude (degree E)
Fulbaria	GT6120007	24.62	90.26
Iswarganj	GT6131018	24.69	90.60
Muktagacha	GT6165022	24.76	90.26
Mymensingh Sadar-1	GT6152021	24.72	90.39
Mymensingh Sadar-2	GT6152020	24.75	90.40
Mymensingh Sadar-3	GT6152017	24.77	90.40
Trishal	GT6194038	24.58	90.39

2.3 Spatial analysis

The inverse distance weighting (IDW) approach was used to map the spatial distribution pattern of the groundwater level. To predict a non-sampled point, IDW was employed, that consider the weighted average of identified values within its immediate vicinity (Lu and Wong, 2008). According to Islam et al. (2019), it is simple to use and adaptable when it comes to interpolating spatial data. This strategy is more effective compared to other interpolation methods. We have carried out the IDW interpolation using QGIS 3.4. According to each monitoring station's location (latitude and longitude), matching groundwater level data were assigned. The assigned values were then spatially distributed over the study area using the IDW interpolation method.

2.4 ARIMA modeling

Autoregressive integrated moving average (ARIMA), a reliable model frequently used to model time series data and predict future data in a series, was used to forecast the water level variations in the study areas (Akhter et al., 2019a; Islam et al., 2019). Three parts make up this model: moving average (q), integrated (d), and autoregressive (p) (Islam et al., 2021). The component p is used for prediction, while the d removes the non-stationarity, and the component q is used

for adjusting the future prediction (Islam et al., 2021; Bibi et al., 2014). ARIMA modeling is a widely used stochastic approach for predicting water resource variables (Bibi et al., 2014; Akhter et al., 2019a). The R software (version 4.3.0) was used to perform the ARIMA modeling analysis. The model can be expressed as equation (1):

$$Y_t = \alpha + \beta_1 Y_{t-1} + \cdots + \beta_p Y_{t-p} + \varepsilon_1 \qquad (1)$$

Where, Y_t is the forecasted value at time t, Y_{t-1} is the previous forecasted value, α is the constant term, β is autoregressive parameter and ε is moving average parameter. For the present study, forecast and auto Arima packages were used for prediction by 2050.

3. Results and discussion

3.1 Variation in climatic conditions

The development of forecasting tools for temperature, precipitation, and groundwater level can be facilitated by any observed time series datasets at regional scales. This will enable the sustainable use of current water resource practices (Islam et al., 2021). The yearly average rainfall amount at the BWDB's Mymensingh station is depicted in **Figure 2**, which displays a fluctuating trend. The year 2012 saw the lowest recorded rainfall of 1,200 mm, while the years 2002, 2007, 2017, and 2023 saw the highest recorded rainfall of more than 2,200 mm. Any region's rainfall may act as a natural recharge of aquifers, but uneven rainfall can have an adverse impact on recharge processes (Taylor et al., 2009).

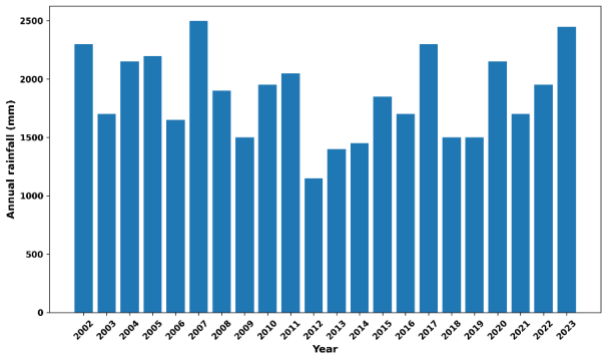

Figure 2. *Average annual rainfall in the study area.*

3.2 Spatial distribution of groundwater level

The groundwater level distribution maps showed that the depth fluctuated both spatially and temporally. The apparent variation of the groundwater level in the study area is shown in **Figure 3**. The station in the center of the study areas, GT6152021, had the highest depth to water table, ranging between 9 m and 14.32 m, whereas GT6131018, located in Ishwarganj upazila, had the lowest depth, measured between 5 m and 9 m. From 2002 to 2023, there was a steady

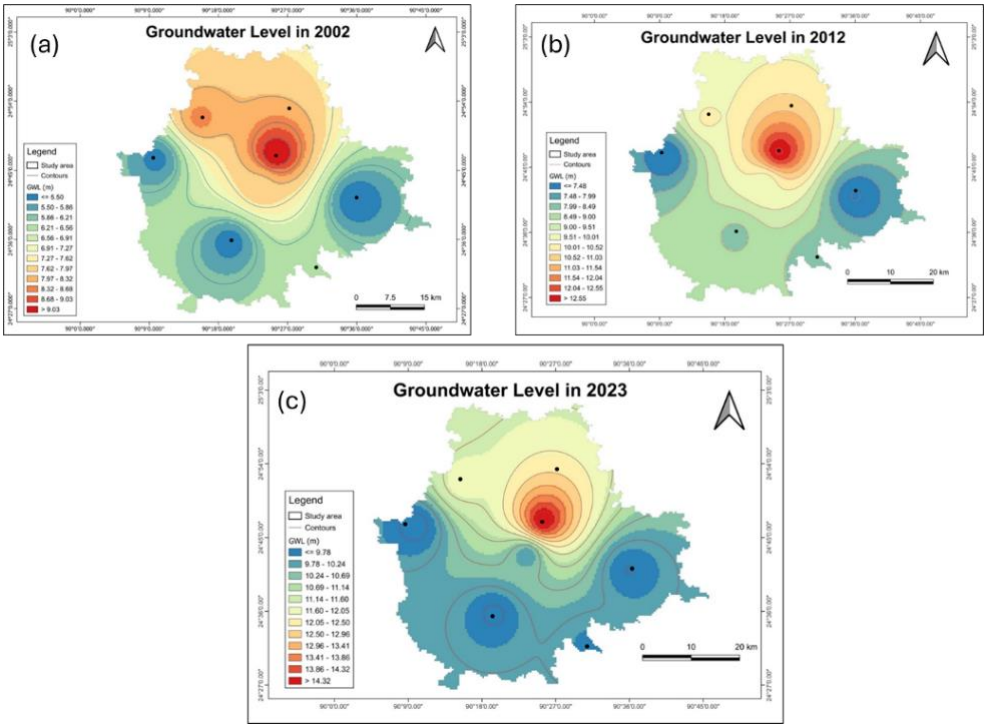

Figure 3. *Groundwater level distribution in the study area in a) 2002, b) 2012, and c) 2023.*

declining trend in the groundwater level in the other monitoring wells. In Muktagacha, Fulbaria, and Iswarganj upazilas, groundwater level fluctuations were found to be seasonal. The annual minimum water table depths in Muktagacha and Fulbaria increased steadily over time, whereas those in Iswarganj remained relatively stable, indicating that annual groundwater losses in Muktagacha and Fulbaria were not fully replenished during the wet season (Zaman, 2007).

Table 2 showed that, out of the seven monitoring wells, GT6152021 had the highest rate of decline (0.24 m/year) and GT6152020 had the lowest rate of decline (0.09 m/year). The annual depletion rates for GT6152017, GT6165022, GT6131018, GT6120007, and GT6194038 were 0.15 m, 0.18 m, 0.19 m, 0.18 m, and 0.15 m, respectively. The monitoring wells within the study area exhibited a declining trend in the groundwater level, indicating that excessive extraction of groundwater resources was occurring in this area. In comparison with the other years, the larger groundwater extraction had occurred between 2017 and 2023 (**Fig. 4**). This problem may be caused by an increase in construction activity, population growth, and unpredictable rainfall pattern.

It was observed that in the Joypurhat district, the distribution of rainfall, temperature, evapotranspiration, and the amount of groundwater pumped could influence the apparent change of groundwater level (Rashid et al., 2022). The rate of groundwater level decline increases during the dry season due to the climatic condition, excessive groundwater pumping for irrigation, and low rainfall. Similar reasons were influencing groundwater level variations in the study area, which led to unsustainable utilization of groundwater resources. Previous research revealed that the yearly maximum water table in wells located in the Fulbaria and Muktagacha upazila exceeded the shallow tube wells' suction limit (Zaman, 2007). To address this issue, several communities in the study area installed additional suction pumps at deeper elevations for the distribution of fresh water, which adversely affected both the environment and human living (Tabassum and Seddique, 2025).

Table 2. *Average rate of depletion of groundwater level of monitoring wells in the study area.*

Location	Station ID	Water level (m)		Rate of depletion (m/year)
		2002	2023	
Fulbaria	GT6120007	5.87	9.83	0.18
Iswarganj	GT6131018	5.6	9.78	0.19
Muktagacha	GT6165022	5.8	9.76	0.18
Mymensingh Sadar-1	GT6152021	9.38	14.66	0.24
Mymensingh Sadar-2	GT6152020	6.47	8.45	0.09
Mymensingh Sadar-3	GT6152017	8.43	11.76	0.15
Trishal	GT6194038	7.28	10.58	0.15

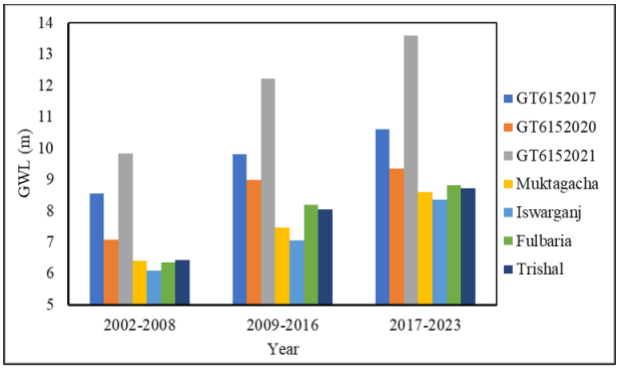

Figure 4. *Changing pattern of groundwater levels (average over the years) in the monitoring wells at different years.*

3.3 Predicted groundwater level using ARIMA model

The ARIMA time-series model was used to predict groundwater levels in the study area. Most of the wells were predicted using the (0,1,0) model, which indicated a basic random walk model with the prior value plus a random step (**Table 3**). The Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) represented the model's prediction errors. The models were generally simple and worked well in most situations. The predicted levels revealed significant differences in groundwater depth across the study area, with some areas facing critically low water tables.

Figure 5a illustrates the changes in groundwater level in GT6152021 until 2023, when it was expected to reach approximately 15 m. The fitted model (0,1,0) predicted that if the depletion persists, the water level will reach approximately 25 m or higher. The water level at stations GT6152017, GT6152020, GT6165022, GT6131018, GT6120007, and GT6194038 was determined to be 11.78 m to 19 m, 10.03 m to 17.5 m, 9.33 m to 19.5 m, 9.49 m to 18.5 m, 9.43 m to 17.5 m, and 9.73 m to 17.5 m, respectively (**Figure 5b–g**). There was a minor negative impact on the distribution of rainfall and the climate. However, a major factor influencing the declining trend in groundwater levels

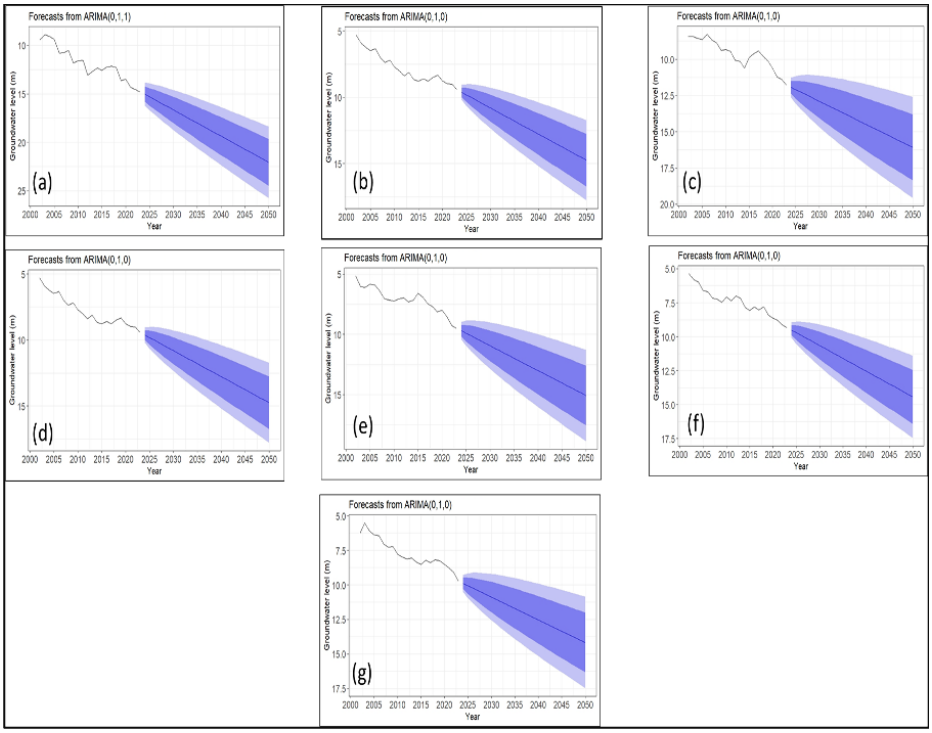

Figure 5. *Groundwater level forecasting from ARIMA in 2050 for (a) Mymensingh Sadar-1 (GT6152021), (b) Mymensingh Sadar-2 (GT6152020), (c) Mymensingh Sadar-3 (GT6152017), (d) Fulbaria, (e) Iswarganj, (f) Muktagacha, (g) Trishal. The blue shade revealed the predicted water level by 2050.*

may be the increasing demand for groundwater for irrigation associated with agricultural development in the study area. One of the main causes of groundwater level depletion in the studied region may be attributed to overexploitation of the aquifer, which offsets fluctuations in surface water flow rate and the balance between supply and demand (Tabassum and Seddique, 2025). Surface water-groundwater interaction is a complex system that depends on several variables, such as the aquifer type, soil texture, stream water altitude, and groundwater table height, in relation to each other. Other factors, such as annual rainfall, groundwater abstraction, and local subsurface geological conditions, also influence long-

Table 3. *Performance metrics for groundwater level prediction in the training stage.*

Location	Station ID	Fitted model	Root Mean Square Error (RMSE)	Mean Absolute Error (MAE)
Fulbaria	GT6120007	0, 1, 0	0.11	0.21
Iswarganj	GT6131018	0, 1, 0	0.15	0.11
Muktagacha	GT6165022	0, 1, 0	0.23	0.15
Mymensingh Sadar-1	GT6152021	0, 1, 1	0.93	0.32
Mymensingh Sadar-2	GT6152020	0, 1, 0	0.12	0.10
Mymensingh Sadar-3	GT6152017	0, 1, 0	0.19	0.20
Trishal	GT6194038	0, 1, 0	0.13	0.09

term changes in groundwater level. Since precipitation is the main source of groundwater recharge, changes in it can have a substantial impact on the groundwater level. Previous research suggested that Bangladesh's rapidly declining groundwater levels are linked to the overextraction of groundwater for irrigation (Chowdhury and Islam, 2022; Faruki Fahim et al., 2024).

This study relied on groundwater-level data from only seven monitoring wells, which might not accurately reflect spatial variability across the study area. Because groundwater abstraction data were lacking, pumping consequences were estimated indirectly using groundwater-level patterns. Spatial interpolation using the IDW approach created uncertainty, especially in areas far from monitoring stations. Furthermore, ARIMA-based predictions presupposed the permanence of previous trends, and the lack of a physically based groundwater flow model restricts process-level interpretation.

4 Conclusion

This study found that for the previous 20 years, the groundwater level in the study area had been continuously declining. Out of the seven monitoring wells, GT6152021 (0.24 m/y) had the highest rate of depletion while GT6152020 (0.09 m/y) had the lowest; both are in the Mymensingh Sadar. The other wells had a depletion rate of 0.15–0.19 m/y. The long-term declining tendency suggested that they would continue their current trend in the future. The ARIMA modeling results aligned with the prevailing groundwater trends reported in other regions of Bangladesh. According to the fitted model, the groundwater level for GT6152021 would reach 25 m by 2050, while the other wells would reach between 17.5 and 19.5 m. If current trends persist, freshwater scarcity will pose a severe threat to future generations, necessitating urgent action from local governments. Rainwater harvesting may be adopted as a long-term solution to manage such adverse effects. In the short-term, regular groundwater level monitoring would inform policymakers or regulators of the current trend. Future research should investigate the relationship between groundwater level fluctuations and large-scale atmospheric variations, as well as the impact of urban development, in the study region.

5 Data availability statement

The data will be made available upon reasonable request from the corresponding author.

6 Ethical statements

Not applicable for this research.

7 Conflict of interest

The authors declare that there are no financial or personal conflicts of interest that could have influenced the results of this study.

8 Acknowledgement

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9 Author contributions

S. Tabassum: Conceptualization, investigation, data curation, formal analysis, writing – original draft, and writing – review and editing. A.A. Seddique: Methodology, supervision, and writing – review and editing. All authors approved the final version of the manuscript.

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